ENGINEERING DESIGN OPTIMIZATION ALGORITHMS: THEORY AND PRACTICE

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Noisy or nonsmooth merit functions are often encountered in computational engineering design optimization. This noise can be caused by the actual physical phenomena being modeled, such as random wave motion or oscillating shock waves, or by artificial means, such as adaptive grid refinement or the incomplete convergence of an iterative solver. The impact of numerical noise is that it creates discontinuities in the value and/or gradient of the merit function. From a theoretical viewpoint, this violates some of the basic assumptions on merit function continuity and convexity that are required by many gradient-based optimization algorithms. From a practical perspective, gradient-based optimization methods can still be applied to noisy merit functions, but these optimization methods often become trapped in artificial local optima that are far from the true optimum. Non-gradient optimization methods can be applied to merit functions that contain numerical noise, but these algorithms often are too computationally intensive for use on high-fidelity computational engineering applications where the cost of a single merit function evaluation can be measured in hours or days of compute time.

Surrogate-based optimization (SBO) methods have been developed for use on computationally expensive engineering optimization applications involving noisy merit functions. Here, the term “surrogate-based” refers to the use of a low-fidelity, low-cost merit function that approximates the behavior of the original merit function. In SBO, the optimization algorithm operates on the low-fidelity merit function, and employs periodic calibrations so that the low-fidelity merit function remains faithful to the original merit function. The low-fidelity merit function can take the form of a multidimensional surface fit (e.g., polynomial regression or spline interpolation), or the low-fidelity merit function can be physics-based if it neglects some of the complexity found in the original merit function. In either scenario, a key desired feature of the low-fidelity merit function is that it provides at least a C^1-continuous function that is amenable to gradient-based optimization. In cases where C^1-continuity can be guaranteed for both the low-fidelity and original merit functions, the SBO algorithm is provably-convergent to a local optimum. However, in engineering design cases where continuity is often not satisfied, SBO can be applied as a computationally efficient heuristic global optimization method.

The SBO method presented here builds on the work of Alexandrov, et al. [1], and Giunta and Eldred [2]. The mathematical underpinnings of the SBO algorithm will be discussed, along with results obtained from applying the SBO algorithm to various example problems and engineering design studies.

References

[1] Alexandrov, N. M., Dennis, Jr., J. E., Lewis, R. M., and Torczon, V., “A Trust-region Framework for Managing the Use of Approximation Models in Optimization,” *Structural Optimization*, v. 15, p. 16-23, 1998.
[2] Giunta, A. A., and Eldred, M. S., “Implementation of a Trust Region Model Management Strategy in the DAKOTA Optimization Toolkit,” in Proceedings of the 8th AIAA/USAF/NASA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, Long Beach, CA, AIAA Paper 2000-4935, Sept. 6-8, 2000.

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